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An Agent-Based Model for Exploring Land Market Mechanisms for Coastal Zone Management

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Abstract: This paper presents an agent-based model of a land market (ALMA-C) to simulate the emergence of land prices and urban land patterns from bottom-up. Our model mimics individual decisions to buy and to sell land depending on economic, sociological and political factors as well as on the characteristics of the spatial environment. To this we add ecological and environmental considerations and focus on the question of how individual land use decisions can be affected to reduce the pressure on the coastal zone ecosystem functions. A series of model experiments helps visualize and explore how economic incentives at a land market can influence the spatial distribution of activities and land prices in a coastal zone. We demonstrate that economic incentives do affect urban form and pattern, land prices and welfare measures. However, they may not always be sufficient to reduce the pressure on coastal zone ecosystems.

Keywords: agent-based modelling; coastal zone ecosystems; land market mechanisms.

1. INTRODUCTION

Coastal zones (CZ) are important from both ecological and socio-economic points of view (Martínez, Intralawan et al. 2007). These are one of the most productive areas on our planet that provide many ecosystem services such as erosion control and sediment retention, habitat for species, food production, recreation and others (Costanza, d'Arge et al. 1997). Like other ecotones these areas are especially rich in biodiversity and have one of the highest values for ecosystem services per hectare of area. CZs require a delicate balance between human-dominated systems and ecosystem functions provided by interactions of land and sea. This makes protection of CZs in their pristine form an important component of environmental management. Unfortunately, CZs are also very lucrative area for development. CZs are also one of the most densely populated areas housing two thirds of world's population (Costanza, Andrade et al. 1999). Particularly in the Netherlands 70% of the Gross National Product today is generated in the CZ (Veraart, Brinkman et al. 2007). Pressure on CZ induced by economic activities causes the disruption of coastal ecosystem functions including modification of a shoreline, reduction of habitat's carrying capacity and diminishing recreational value of coasts (Costanza, Andrade et al. 1999; Martínez, Intralawan et al. 2007). Waterfront properties are known to be several times more expensive than similar properties inland. People are willing to pay high prices for water view and water access. These areas have been also historically developed due to proximity to marine and river transportation. Further developments occur in the proximity to historic cities causing even more buildings constructed in areas vulnerable to flood or erosion. According to IPCC the damage from natural disasters has rapidly increased over the past decades due to the growth of capital in flood-prone areas (Nicholls, Wong et al. 2007). Thus, in addition to contributing to the deterioration of coastal ecosystem functions economic activities located in CZ are subject to flood risks. The potential damage from flooding/erosion depends on the economic value of land and concentration of economic activities or residential areas.

If we are to protect CZ ecosystem services we need to find ways to create disincentives for people allocation near the coastline. Using economic incentives to achieve environmental goals can be much more efficient than traditional command and control regulation, if the incentives can be put in place and enforced at relatively low cost (Costanza, Andrade et al. 1999). *What can be the economic incentives and market mechanisms that would reallocate population out of the CZs?*

In this paper we present a simple agent-based model that integrates heterogeneous landscape, explicit individual location choices via land market to explore the influence of economic incentives on the aggregated spatial pattern of the urban area. Since the area occupied by urban developments actually takes over the land that provides ecosystem functions in CZ, this aggregated pattern indirectly shows how much pressure is put on the CZ ecosystems.

2. THE MODEL

Our *Agent-based Land MArket for Coast* model (*ALMA-C*) simulates the emergence of urban land patterns and land prices as a result of micro-scale interactions between buyers and sellers of land with application to a coastal city. The main agents in the model are traders, spatial goods (i.e. land lots) and a market (see Figure 1).

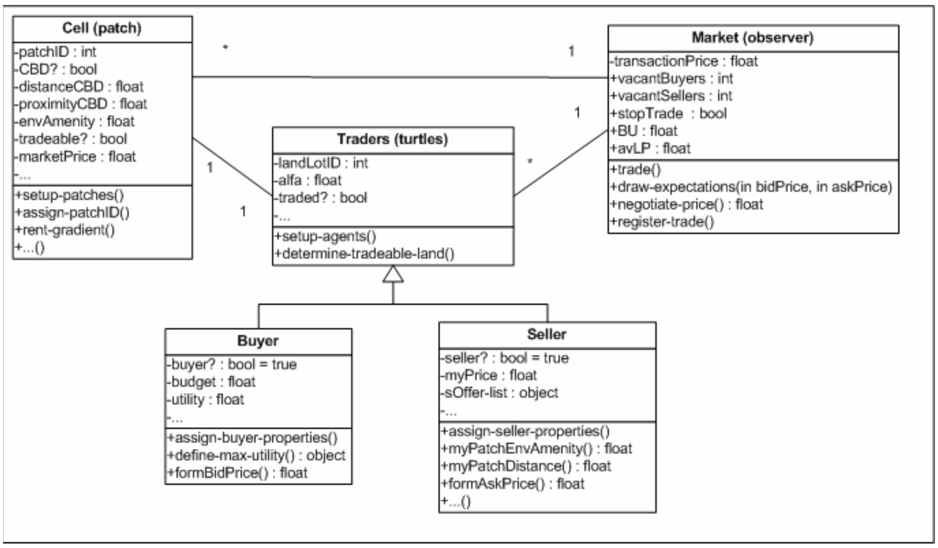

Figure 1. UML class diagram of the ALMA metamodel

The core of the model is presented by a land market (Filatova, Parker et al. 2007; Filatova, Parker et al. under submission). ALMA-C borrows much from the analytical monocentric urban model (Alonso 1964) and its application to a city with green amenities (Wu and Plantinga 2003). In line with the assumptions of the analytical model the ALMA-C model assumes that each spatial good is differentiated by distance (*D*) from the central business district (CBD) (or its inverse measure – proximity $P=D_{max}+1-D$) and level of environmental amenities (*A*) (estimated as a normalized distance to the coast). Other attributes of land can be easily added if needed. Buyers (i.e., households) search for a location that maximizes their utility $U = A^{\alpha} \cdot P^{\beta}$ (ά and β are individual preferences for green amenities and proximity correspondingly) and is affordable to their disposable budget for housing net of transport costs (*Y*). The rationality of agents is bounded by the fact that they do not search for the maximum throughout the whole landscape but rather search for the local maximum among N randomly chosen cells. We impose this assumption since the search for a house in reality is very costly (time-wise and money-wise), meaning that a global optimum is not likely to be located in real-world housing markets. After defining the spatial good that gives maximum utility a buyer forms the bid price. A bid price is a function of utility (*U*), individual income (*Y*) and prices of all other goods (influence of which is expressed by a constant *b*): $P_{bid} = \frac{Y \cdot U^n}{b^n + U^n}$. The justification and properties of this demand function are discussed in details in (Filatova, Parker et al. under submission). Sellers form their bid prices also depending on their utility, bit their ask price do not go below the price of an open space area (P_{nat}).

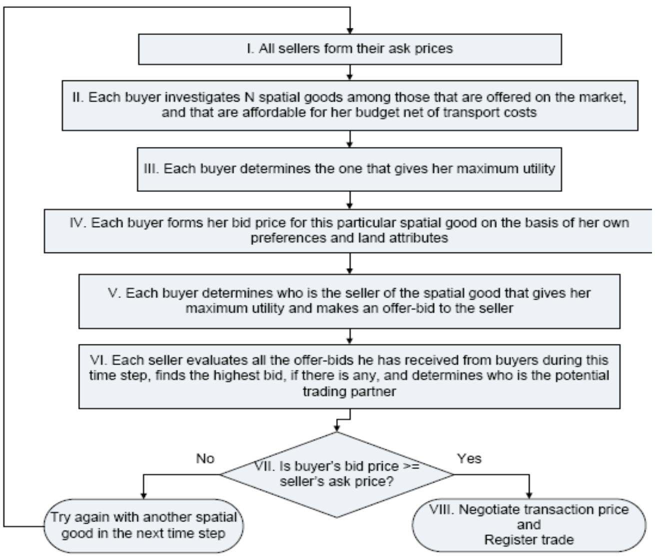

Figure 2. Conceptual algorithm of trade

Having found the optimal location, buyers submit their offer-bids to the sellers. Sellers choose the highest bid-offer and if it is above their ask price, then the transactions take place. If not then both buyer and seller participate in the land market in the next times step. The final transaction price is an arithmetic average of the ask price and the highest bid price. Figure 2 shows the logic of the trading mechanism, i.e. one time step in the model (more about event sequencing in (Filatova, Parker et al. under submission)).

Let us suppose that in attempt to protect the coastal ecosystem services we are introducing a tax to make coastal properties more expensive and less affordable. Suppose we calculate the amount of tax to be paid as $T = tr \cdot P_{nat} \cdot P_{amen}$, where *tr* is a tax rate in % and P_{amen} is proximity to the coast.

3. SIMULATION EXPERIMENTS

Running the model we can produce spatially explicit land price gradients and land patterns as simulation results. We are mainly interested in how the introduction of a land tax, aimed to protect CZ ecosystems, affects economic indicators and the spatial morphology of the city. In addition to graphical representations, we also present a set of metrics to analyze micro and macro economic and spatial outcomes (listed in Table 1 below). Our major metric of success with respect to the ecosystem services preservation is the number of undeveloped cells within the prime coastal zone, which is defined as the stripe of land covered by 7 cells wide along the coast (all the zone that lies to the left of the CBD). We will call this zone *CZ buffer*.

All model experiments presented in this paper were performed on a 31x51 grid of cells with part of the landscape (5x cells) representing sea and a coastline. The CBD was set at the cell with coordinates (-4;0). There were 2652 buyers and sellers participating at the land market. The price of the natural area (P_{nat}) was set equal to 200. We run the model with agents having homogenous preferences for green amenities, i.e. for the view on the coastline, ά = 0.7. Although the code of the ALMA-C model allows simulation of a land market with heterogeneous agents, we did not use this possibility here to keep clarity. Transport costs per unit of distance were equal to 20 units, the constant b in (1) was equal to 70.

To understand the influence of such an economic incentive as tax on the aggregated outcomes we ran a series of 13 experiments. We changed only two parameters in the experiments: tax rate and individual income, which both affect households' willingness to pay for the house in the coastal city. Each experiment is associated with the value of tax and income, specifically experiment "3-900" means that we ran the model with a land tax equal to 3% and individual income equal to 900 units. We show the outcomes of 7 representative experiments in Table 1 and discuss the results of the others below.

Table 1. Economic and spatial metric outcomes of the ALMA-C experiments

Parameter	0-800	5-800	5- ND 800/20	0-900	5-900	0-1000	5-1000
Individual utility: Mean	73.17	71.86	72.68	70.26	70.59	67.79	68.15
St. dev.	11.13	10.82	11.41	12.14	12.18	12.98	12.87
Aggregate utility	36587.71	28672.4	34305.6	43494	40450.55	49082.77	48254.45
Urban transaction price: Mean	312.67	312.07	318.64	336.61	337.12	361.77	358.07
St. dev.	75.84	73.92	79.49	93.15	90.61	110.15	107.86
Total property value	156335.9	124514.1	147965.8	208363.2	193169.9	261924.4	253515.4
City size (urban population)	500	399	472	619	573	724	708
Undeveloped land in CZ buffer	86	175	117	42	74	6	12
Distance at which city border stops	20.88	18.11	19.23	23.77	22.36	25.71	25.7

We begin with the experiment that replicates the monocentric urban model with amenities such as coastline. The main difference between the simulation experiment and the analytical model is that the centralized equilibrium land price determination mechanism is replaced by a series of bilateral trades distributed in space and time. Individual households endowed with income equal to 800 try to buy a house that maximises their utility in the coastal city. There is no tax for land introduced in this city. The urban land price gradient is presented in Figure 3 and quantitative measures can be found in Table 1, column "0-800". The intensity of grey colour symbolizes the value of land: the darker the colour, the higher the land price. The urban land prices are the highest in the CBD. As in the benchmark case of a theoretical monocentric urban model, the land price gradient is decreasing with distance from the CBD. But because of the presence of the coast, which serves as an attractor for the households and increases value of the land, urban land laying to the left of the CBD has higher prices than the area to the right. The city expansion stops at the location when bid price of a buyer falls below the price of open space. The white area in Figure 3 shows the beginning of open space and symbolizes the city border.

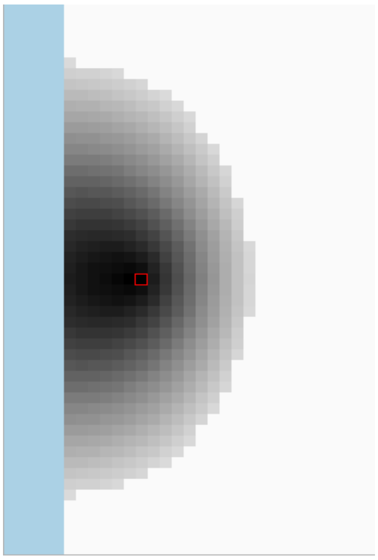

Figure 3. Land price gradients (households income = 800, no tax for land introduced). Red counter shows the CBD.

With the increase of individual income the city significantly expands and CZ buffer representing the amount of open space along the coastline decreases (compare experiments "0-800", "0-900" and "0-1000" in Table 1). So does an average individual utility from location showing that people enjoy less densely populated city, which provides more open space along the coast and less commuting in terms of time and money. In spite of decrease in average utility land prices still grow because the purchasing capacity, i.e. income, has increased.

We proceed with demonstration of changes in the location behaviour of households changes if an environmental tax on land is introduced. The idea is that now agents have to pay extra money for location closer to the coast, assuming all other factors are the same. If this happens then demand for these locations goes down, since it becomes harder to find buyers that could afford to buy there. The market mechanisms start to work. Since our model is not only demand-driven, meaning that land prices are determined via bilateral trades with sellers, the bid price that buyers offer is below the ask price (which also depends on the spatial characteristics of the land lot, but it could not be lower than the land price of the natural area). In this case the transaction simply does not occur and land lot is not occupied by an urban land use.

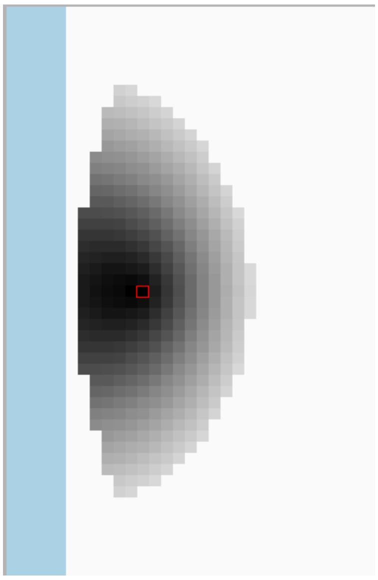

Figure 4. Land price gradients (households income = 800, and land tax = 5%). Red counter shows the CBD.

Let us set the tax equal to 5% of the land price of the natural area. The land price gradient is presented in Figure 4. First of all, the spatial form of the city has changed. The area closer to the coast became less attractive for households to pay more to cover the threshold of the P_{nat}. The households in this experiment basically "voted with their feet" in favour of living in another town because living on the coast now bears additional costs. As a result a lot of land in the "primary" CZ was left unsold and remained in natural conditions. A positive sign is that the CZ buffer has significantly expanded: it became 103% larger than in the city without the land tax aimed to preserve CZ (compare columns "0-800" and "5-800" in Table 1).

The results of experiment "5-800" indicates that in the absence of real markets for the environmental services provided by the CZ economic incentives, such as taxes imposed by the government, may help to influence the land market to achieve more environmentally friendly land use patterns. However, the outcome can change quite dramatically if we open up the market and raise the limit on individual budgets. Effectively this means that we are inviting buyers that are more affluent to come from elsewhere and enter the market.

We repeat the second experiment but assuming that richer households enter this urban land market (we set tax equal to 5% and incomes equal to 1000 units). The results are presented in Table 1 (see "5-1000") and in Figure 5. Thus, in the presence of more affluent households the city not only expands over the borders of the city in the experiment "5-800" (Figure 4) but overflows the boundaries of the city without land tax (experiment "0-800", Figure 3). High-income agents can afford to pay additional costs in terms of the land tax and, thus, settle along the coastline. This fact can often be observed in reality: the wealthiest individuals buy houses with a view on the coast. As a result the CZ buffer has shrunk to 93% of what it was when agents' income was 800 (see "5-800").

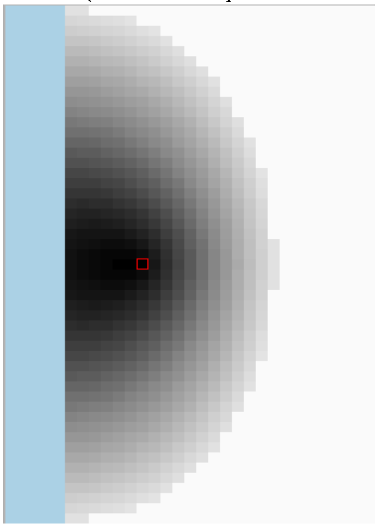

Figure 5. Land price gradients (households income = 1000, and land tax = 5%). Red counter shows the CBD.

On the other hand, in reality not all people have equally high incomes. There is a certain distribution of incomes in the city. Figure 6 shows the land price gradients in the case when we run the model for the population of agents with heterogeneous incomes and land tax rate of 5%. Individual incomes follows normal distribution with mean 800 and standard deviation of 20 (see experiment 5-ND 800/20 in Table 1). There are some households with income higher than average of 800 (as in experiment "5-800" and "0-800"), which can afford to buy houses in the CZ buffer and pay a land tax. However, market incentives still work and part of CZ buffer became vacant (117 instead of 86 in the case without land tax).

In fact, the last three experiments ("5-800", "5-1000" and "5-ND 800/20") showed that economic incentives work only if agents have fixed income. If taxes are introduced but the higher-income households enter the land market then the effect of the tax introduction is eliminated. The introduction of the tax and increase in household incomes drive spatial and land price dynamics in opposite directions. In this case we were interested to investigate the relationship between these two factors. We performed a series of additional experiments with tax rates changing from 0% to 7% and income changing from 800 to 1000. The results in terms of the CZ buffer area remained undeveloped are presented in Table 2.

Table 2. Number of undeveloped cells in the CZ buffer under different tax rates and income values

	Individual income		
Tax rate	800	900	1000
0%	86	42	6
3%	92	46	10
5%	175	74	12
7%	314	247	158

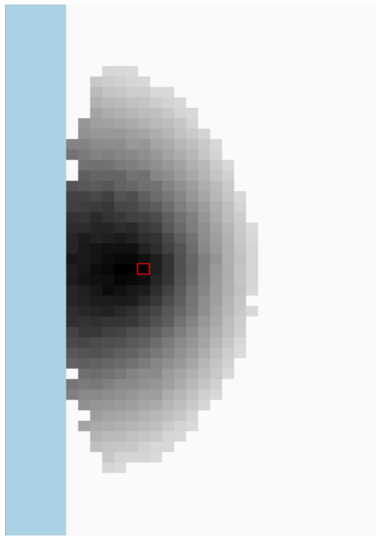

Figure 6. Land price gradients (households incomes follow normal ditribution and land tax = 5%). Red counter shows the CBD.

Visually the relationship is presented in Figure 7. One can see that in the zone of high income the increase in tax gives very small effect on the CZ buffer

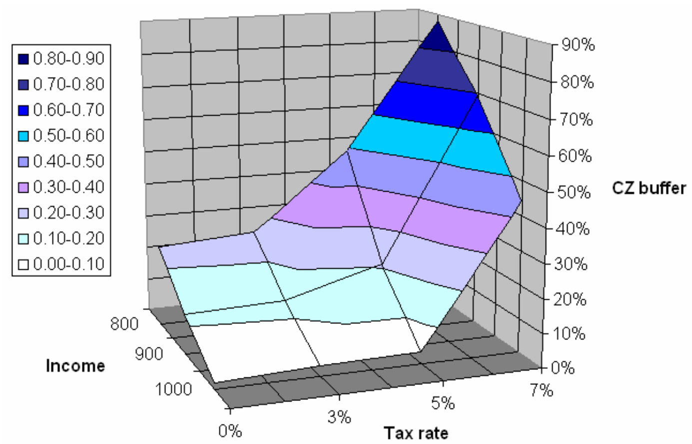

Figure 7. The percentage of CZ buffer not occupied by urban land use

4. DISCUSSION AND CONCLUSIONS

The paper aims at exploring the effects of economic incentives on CZ ecosystem services. At this stage we are interested in general qualitative trends of the ecological – economic system. We used artificial data for both the agents' behaviour and the spatial environment. However, the structural validation of the model was performed (Filatova et al. 2007). The main difficulty of applying ABMs to the real world cases and model validation is in acquiring data about people's preferences and perceptions. As a part of a more general survey on risk of flood perception carried out in March 2008, we created a questionnaire about individual preferences for locations, including preferences for coastal environmental amenities and individual risk perceptions. As the next stage of model development we plan to integrate survey data (when statistical analysis is available) into the agents' behaviour in our ABM.

The model has shown that economic incentives may help in managing the urban development in CZ but may not necessarily produce the desired outcome. For example, the environmental tax instead of protecting the CZ by driving population away from the coast results in attracting more affluent residents – something clearly observed in reality. The CZ becomes populated by MacMansions, which still may have a positive effect on the environment assuring less residential density. The problem then is that environmental quality can potentially lead to social injustice and unrest. The environmental tax drives people away from their native habitats, which then get developed and shaped for the more affluent residents. The ABM helps quantify some of these impacts and analyze trends and spatial patterns as emerging outcomes of individuals interacting at the land market.

Different residential patterns may occur if we bring risk perception into consideration. While CZs and waterfront are attractive residential factors, they become also associated with higher risks of natural disaster (hurricanes, floods, etc.). These are likely to be more frequent with global warming and climate change. As a result, chances are that in addition to environmental taxes, insurance policies are likely to kick in, when insurance companies will deny insurance for properties located too close to the coast. In this case risk perception may become another major component in addition to affluence that will govern the patterns of allocation for residents. Incorporating these processes into our model is the next step in our research.

With a lack of markets for ecosystem services there should be other indirect economic mechanisms for CZ management, which would help account for these services in the decision making process. Developing tools for visualization and scenario analysis, such as the ALMA-C model, is an important prerequisite of environmentally sound land use planning.

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